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# CUTANEOUS THERMOGRAPHY WITH LIQUID CRYSTALS*†

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Preliminary studies by the authors, and others, in 1964 indicated that liquid crystal film provided a new means for the demonstration and quantitation of skin temperature patterns (1). The purpose of this paper is to describe this liquid crystal film technic in greater detail, and to report adaptation of it to certain experimental situations useful in the study of diseases of the skin.

## *Liquid Crystals*

Liquid crystals constitute a class of matter unique in exhibiting mechanical properties of liquids and optical properties of solids. In the liquid crystal state constituent molecules are neither fixed firmly in three dimensional array as in ideal solids, nor free to form random patterns as in ideal liquids. They are formed instead into structured layers which are free to slide over one another, or to revolve about a fixed axis.

Thin films of certain liquid crystal substances, particularly derivatives of cholesterol, exhibit the optical phenomenon known as *selective scattering*. When illuminated with white light, these substances transmit certain wavelengths, scatter back others, and absorb none. The color and intensity of the light scattered depends on the nature of the substance, the temperature, and the angle of incidence of the illumination.

Cholesteric liquid films exhibit another optical property known as *circular dichroism*, the selective scattering of right- or left-handed polarized light. When white light is directed at these substances the light is separated into two components, one with the electric vector rotating clockwise, the other counterclockwise. One component is transmitted, one scattered. The wavelengths scattered depend on the nature of the substance, the temperature, and the angles of incidence and view (2).

Because of these optical properties, films of cholesteric liquid crystals change color with temperature change. They do so reversibly, and with minimum time lag (ca. 0.2 seconds). The temperature level at which these color changes begin, and the width of the range through which the color change takes place, can both be controlled by mixing together various cholesteric substances, and by varying the proportions within the mixture.

We have, then, a tool for the conversion of moving or static temperature patterns into visible color patterns, adjustable to any temperature level of biologic interest, and continuously variable in sensitivity.

## *Cutaneous Thermography*

The application of thin films of liquid crystals to human skin makes possible a new type of cutaneous thermography. Temperature-wavelength curves for a number of the mixtures manufactured under the name "Spectratherm" * are shown in Figure 1. Other ranges can easily be made.

## *Technic*

To prevent light transmitted by the film from reflecting back from the skin surface and obscuring the selectively scattered colors, it is necessary first to apply a black base coat.

A mixture suitable for this purpose is made up of carbon black and polyvinyl alcohol.

The base coat must be applied as uniformly as possible or "brush mark" artifacts will occur from uneven conduction of heat through to the crystal. A commercial air brush such as the Paasche, type H, with a No. 3 tip works well. It is advisable to spray an area several cm. beyond the experimental field to which the crystal

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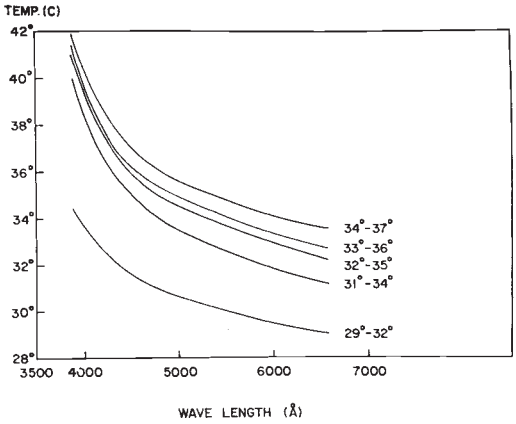



FIG. 1. Temperature wavelength curves for five of the liquid crystal solutions available for cutaneous thermography.

is to be applied. Diffusion of skin lipids into the crystal will otherwise occur, shifting the temperature level at which the color changes take place.

The liquid crystal is applied over the dried base coat, again with a commercial air brush, with a No. 2 tip.

Since the color of the film varies with the angle of view as well as the temperature, it is best to study highly curved areas, such as the fingers, in small sections. For pharmacologic studies requiring large areas, the lumbar portion of the back is most suitable. The flexor surface of the forearm so frequently used in studies of this kind shows large venous patterns which can disturb the development of clear-cut isothermic wave fronts.

Following the application of the liquid crystal film, a brief period ensues with no visible change during which the solvent (usually petroleum ether) evaporates. When the range of the liquid crystal selected includes the temperature of the skin beneath, a brilliant iridescent color pattern will appear, red at the cool end, progressing through the spectrum to blue-violet at the warm end. The black of the base coat shows through when the film is off scale in either direction.

Portable films for clinic use can be made from ordinary embroidery hoops. *Mylar film (0.1 mil) is stretched evenly in the hoop, coated on the skin side with black enamel, and on the viewing side with a suitable liquid crystal mixture. It is convenient for preliminary investigations to have several hoops available reacting at different temperature levels. By resting the hoop on the skin, temperature patterns can be demonstrated at the bedside. The resolution, however, is much inferior to that obtainable with material applied directly to the skin.

*Registered Trade Mark, Dupont, Circleville, Ohio.

*Experimental situations and results*

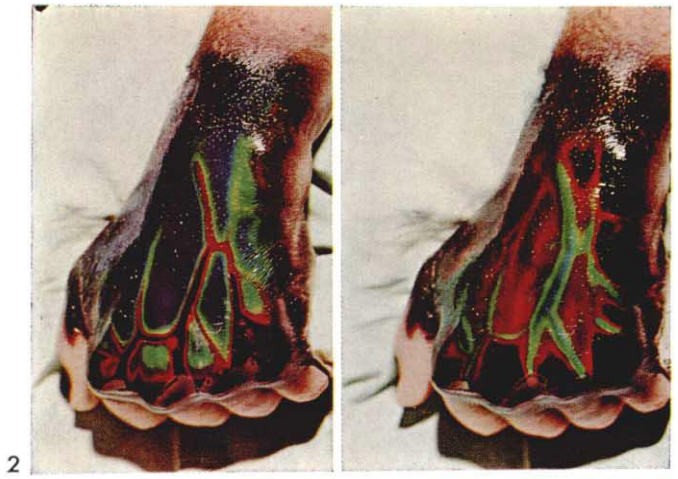
Normal and abnormal venous patterns are well demonstrated by this technic, particularly in the extremities where the thermal gradient between the blood within the vessels and the skin they traverse can be heightened by cooling or heating at points of maximum surface ramification such as the fingers or palms (Fig. 2).

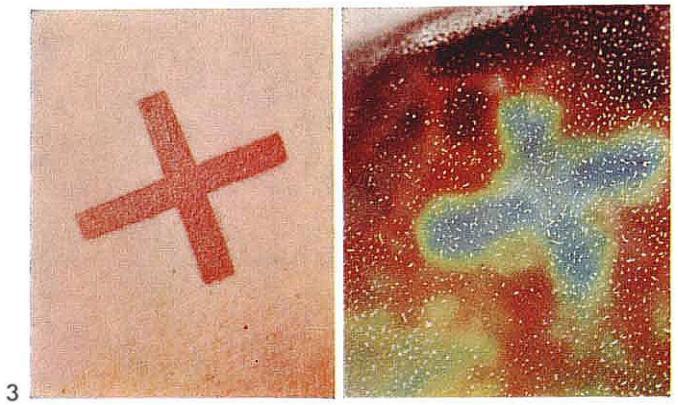
It is clear from our initial studies that the temperature pattern of the general integument is far more complex than previously demonstrated. With narrow range films (1.5° C) it can be shown that no area of skin more than a few square cm. exists at a uniform temperature (Fig. 4a), and our experiences suggest that uniformity may exist only in areas of millimeters.

A complete thermographic map of the human integument is needed. Studies in this direction are already under way and will be the subject of later communications. Distinctive individual thermograms persisting weeks and months have been recorded in areas studied in our subjects. In addition to providing the background color pattern which it is necessary to record to evaluate changes induced by drugs and manipulations in the experimental field, these normal thermograms may offer a means of individual identification to add to dermatoglyphics, retinal vessel patterns, and others already in use. Much more work will have to be done to ascertain which patterns are permanent and which transient, which species specific and which characteristic only of the individual.

A study of the complexity of the patterns shown in Figure 4 should make one cautious in interpreting temperature readings taken from skin with thermocouple or thermistor devices, particularly when the devices are removed between observations, or when different supposedly symmetrical areas are compared.

The technic readily demonstrates the temperature elevations which follow exposure of skin to erythema doses of ultraviolet light. A stage in one such experiment is shown in Figure 3. To permit ready identification of the radiated site a supra-erythema dose of ultraviolet light





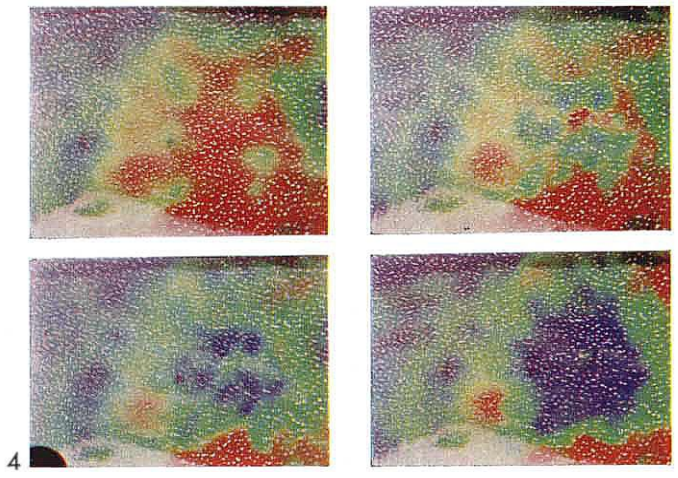


FIG. 2. Venous patterns demonstrated with liquid crystal film. Hand on the left holds a bottle containing water at 0° C. Collecting veins containing cold blood are red, with green gradient zone between them and the warm blue of surrounding skin. Areas too cool to record show as black (34–37° C film).

Hand on the right holds bottle at 42° C. Collecting veins containing warm blood are blue with green gradient zone between them and the cool red of surrounding skin. Ambient temperature of room was lowered for the second picture bringing the basic skin temperature from 37° (blue) down to 34° (red).

Fig. 3. Clinical appearance, and liquid crystal thermogram of ultraviolet induced erythema 4 days after radiation. (36°–37.5° C film).

FIG. 4. Upper left: Normal thermogram of left lumbar area. Field measures 20 × 25 cm. (35°–37° C film). Upper right: Thermogram 3 minutes after injection intradermally of 0.05cc 1:1000 histamine. Injection site red (ca. 35°) with warm green and blue islands developing about it. Lower left: 6 minutes. Further warming. Lower right: 9 minutes. Confluent warm (blue) zone about the injection site, sharply set off from the cooler pattern of normal skin.

was delivered with a General Electric R. S. bulb through an X shaped pattern (legs 7.5 × 1.0 cm.) to the skin of the lumbar area of a 54 year old Caucasian male. At two and three hour intervals the pattern could be seen emerging from the complex normal thermogram. Four days later (Fig. 3) the pattern was very distinct, showing well-demarcated gradients from the warm blue center to the cool red of the normal skin pattern. It is interesting that the duration of the temperature change is considerably shorter than the visible erythema. On the 8th day after radiation, well-marked erythema was still present at the radiation site, but the thermogram had returned to normal, suggesting that the vessels responsible for erythema in later stages are of a caliber too small to alter temperature sufficiently for detection with the crystal film. This new endpoint, uninfluenced by the formation of pigment which interferes with the reflectance spectrophotometric quantitation of ultraviolet light erythema, may prove useful in more sophisticated studies of the effects of electromagnetic radiation on skin, ultraviolet light protection, and related problems.

Liquid crystal films provide a convenient means for visualizing and quantitating the effects of vasoactive drugs injected into the skin. The temperature patterns around histamine wheals are particularly clear. A central cool umbo at the injection site is surrounded by a warmer zone which propagates itself centrifugally, first as a group of discrete oval warm spots which soon coalesce to form a confluent warm zone surrounded by a narrow gradient zone, the transition from the maximum vasodilatation toward the injection site to the cooler pattern of normal skin. Figure 4a shows the normal thermogram for the left lumbar area of a 54 year old Caucasian male. An injection of 0.05 cc of 1:1000 histamine was made intradermally (through the film) into the area. Pictures were made at intervals of approximately 3 minutes. The injection site is identifiable in Figure 4b as the cool central umbo. The stages in the development of the warm blue zone around it are clearly shown in Figures 4b, c, and d.

The intradermal injection of epinephrine results in temperature patterns which show on the liquid crystal film as the reverse of the histamine effect. A cool central umbo at the injection site is surrounded by an intermediate zone warmer than the umbo, but cooler than the surrounding skin. This cool pattern rapidly propagates itself outward into the normal thermogram.

The precision with which these changes can be followed suggests that the technic will be useful in studying the well known disturbances in skin vascular responses in atopic states, and perhaps in quantitating immediate wheal responses in hypersensitivity states.

The usefulness of this technic in the delineation and characterization of deeper tumors such as carcinoma of the breast is under investigation elsewhere (3).

*Recording and Quantitation of Results*

Except for descriptive purposes, the complex thermogram contains too much information to be useful in its entirety. Spectral segments representing corresponding temperature ranges can be isolated from it by photographing on black and white film through interference filters, or with monochromatic light sources. The precision of the measurement, *i.e.* the width of the temperature band, will then be a function of the width of the transmission band of the filter or the band width characteristic of the monochromator. The area of the field existing at a given temperature can then be expressed, using a photographic densitometer, as the ratio of light incident to light transmitted and compared meaningfully to alterations experimentally produced in the experimental field, recorded and expressed in the same manner.

Technical difficulties arise from the extreme shininess of the film. These can be avoided by polarizing light sources and camera lens at right angles.

More sophisticated arrangements involving direct readings from filtered photocells will simplify the recording of color change.

It is possible to record the field on color film and take black and white separations from the transparency, but specular reflection problems then become more difficult. Ordinary polarization is inefficient at the blue end of the spectrum, and fails to eliminate reflections completely. Skillful placement of light sources is necessary.

When isothermic wave fronts move centrifugally, as in histamine studies, simple averaging of distances per unit time is useful. When patterns change rapidly, or very slowly, inter-

mittent still photography is impractical. In these instances cinephotography, slow motion and time lapse, has been employed with success.

In our experimental situations the most useful information has been derived from quantitation of changes in temperature levels with respect to the thermal pattern present at the beginning of the procedure. So long as recording and lighting devices are constant in position throughout the experiment, the color changes recorded will accurately represent proportional temperature changes, regardless of the angles which they form with respect to the plane of the skin. When it is desired, however, to know the exact temperature represented by a given color recorded on film, the geometric relationships of the setup must be taken into account. The temperature-wavelength curves, shown in Figure 1, are determined from normal incident lighting (source perpendicular to film plane). Correction for other angles for light source and recording device can be made by applying the following experimentally verified correction factor:

$$\lambda = \lambda n \cos \frac{1}{2}\left(\sin^{-1}\frac{1}{1.5}\sin\phi_1 + \sin^{-1}\frac{1}{1.5}\sin\phi_2\right)$$

Where

$\lambda$ = wavelength of maximum scattering

$\lambda n$ = wavelength of maximum scattering for normal incidence and observation

$\phi_1$ = angle of incidence

$\phi_2$ = angle of reflection

SUMMARY

1. The optical properties of thin films of liquid crystals are described.

2. A technic is described for the demonstration and quantitation of skin temperature patterns by the application of liquid crystal solutions to human skin.

3. The temperature pattern of normal skin is shown to be more complex than previously believed.

4. Temperature patterns over erythema induced in human skin by ultraviolet light are described.

5. Temperature patterns over sites of intradermal injections of histamine and epinephrine are described.

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